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Pricing Policy and Free Entry in Spatial Competition

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1. Introduction

The major concern of this paper is pricing policy by firms in the framework of spatial competition. Most of the literature on spatial competition do not consider the choice of pricing strategies. Pricing policy is usually predetermined there. For example, among others, Hotelling (1929) assumed mill pricing while Hoover (1937) supposed spatially discriminatory pricing. However, it is the profit-maximizing firms that determine the pricing strategy, i.e., the pricing strategy is not exogenously given, but should be endogenously determined within a model.

Taking account of the firms' choice of pricing strategies, we study the impacts of cost differences on the structure of industries. In reality, mill pricing predominates in some industries while discriminatory pricing prevails in other industries. This may be ascribed to the differences in transportation costs, marginal costs, or fixed costs as explained later in this paper. Furthermore, we examine reasons for the difference in the number of firms between industries, and discuss prospective changes in the industrial structure.

We also conduct welfare analysis. By calculating the social total costs, we obtain the optimum number of firms, and compare it with the equilibrium number of firms. It should be noted that the number of firms in physical space can be interpreted as the number of varieties in characteristics space. So, our analysis is applicable to the case of horizontal differentiation of product specifications.

The organization of this paper is as follows. In Section 2, we describe the model, and explain three kinds of spatial arrangements of pricing strategies. In Section 3, examining sustainability of each equilibrium strategy, we compute dominant strategies for all parameter values. In Section 4, regarding the number of firms as an endogenous variable, we investigate the long run equilibrium, and compare it with the social optimum. In Section 5, we analyze the transition in the spatial arrangement of pricing strategies by changing a parameter value. Section 6 concludes the paper.

2. The Model

There are n firms producing an identical good. For a moment, n is assumed to be fixed, but in the later sections, it is endogenously determined by the zero profit condition under free entry. It is assumed that n is large enough so that no fraction problem arises. Firms choose either mill pricing or discriminatory pricing.

Consumers are uniformly distributed over the unit-circumference of a circle with the density normalized to one, and their location is denoted by $x \in [0,1]$. Each consumer purchases one unit of the good from a firm offering the lowest full price. The full price is defined by the mill price plus transportation cost in the case of mill pricing, and defined by the delivered price in the case of discriminatory pricing. The transportation cost is assumed to be a quadratic function of distance with the identical coefficient of c. It is incurred by consumers in the mill pricing case, and by firms in the discriminatory pricing case. The transaction costs for resale of goods between consumers are prohibitively costly. The marginal costs of production are f^d in the mill pricing case and f^m in the discriminatory pricing case, and the fixed cost of entry is F.

Each firm simultaneously chooses its location on the circumference of a circle in the first stage, and simultaneously selects a pricing strategy and a price (single mill price or delivered price schedule) in the second stage. We thus seek subgame perfect Nash equilibrium. We focus only on symmetric equilibrium due to mathematical tractability although asymmetric equilibrium analysis is important as pointed out by Tabuchi and Thisse (1993).

In this section, we consider the case of the fixed number of firms. Let us denote the profit of firm i by $\pi_i(z_i | z_{i\pm1})$, where z_i is the price of a good purchasing from firm i, and $z_{i\pm1}$ is that purchasing from the two neighboring firms at location $z_{i\pm1}$. If firm i chooses discriminatory pricing, then we set $z_i = p^d(x)$; and if firm i selects mill pricing, then we set $z_i = p^m$. These two price variables will be defined in the next two subsections.

2a. Discriminatory pricing

If each firm chooses the discriminatory pricing strategy, the price schedule of firm i is set equal to the second lowest level of the delivery costs (transportation cost plus marginal production cost) among all firms, which is expressed as

$$\begin{aligned} p^d(x) &= c(x - x_{i-1})^2 + f^d \qquad \text{for } x \in [(x_{i-1} + x_i)/2,\ x_i], \\ &= c(x - x_{i+1})^2 + f^d \qquad \text{for } x \in [\ x_i, (x_i + x_{i+1})/2]. \end{aligned} \tag{1}$$

Note that given the symmetry of cost structures, the market boundaries are the midpoints between two neighboring firms.

For each location x, firm i has to pay the delivery cost and the marginal cost: $c(x - x_i)^2 + f^d$ for $x \in [(x_{i-1} + x_i)/2,\ (x_{i+1} + x_i)/2]$. Hence, the profit of firm i is given by

$$\begin{aligned} \pi_i(p^d | p^d) &= \int_{(x_i - x_{i-1})/2}^{(x_{i+1} - x_{i-1})/2} cx^2 dx + \int_{(x_{i+1} - x_i)/2}^{(x_{i+1} - x_{i-1})/2} cx^2 dx - \int_0^{(x_i - x_{i-1})/2} cx^2 dx - \int_0^{(x_{i+1} - x_i)/2} cx^2 dx - F \\ &= \frac{(x_{i+1} - x_{i-1})}{4}[c(x_{i+1} - x_i)(x_i - x_{i-1})] - F, \end{aligned} \tag{2}$$

where $p^d \equiv p^d(x_i)$. It is not difficult to show that (2) is maximized at $x_i^* = (x_{i+1} + x_{i-1})/2$, $\forall i$. This midpoint location is a consequence of the firms' behavior that they locate as far as possible each other to relax fierce price competition. Substituting x_i^* into (2), and using $x_{i+1} - x_{i-1} = 2/n$ due to symmetry, we can simplify the profit function of each discriminatory pricing firm:

$$\pi_i(p^d | p^d) = \frac{c(x_{i+1} - x_{i-1})^3}{16} - F$$

$$= \frac{c}{2n^3} - F, \tag{3}$$

In Figure 1, the shaded area is equal to the profit of (3).

2b. Mill pricing

Consider the next case that each firm chooses the mill pricing strategy. Let b_i be the market boundary between firm i and firm i+1. Since the marginal consumer locating at b_i is indifferent between i and i+1 in buying a good, the two full prices should be equated as:

$$p_i + c(b_i - x_i)^2 = p_{i+1} + c(x_{i+1} - b_i)^2,$$

or

$$b_i = \frac{p_{i+1} - p_i + c(x_{i+1}^2 - x_i^2)}{2c(x_{i+1} - x_i)}.$$

Figure 2 illustrates the situation. The profit is then given by

$$\pi_i(p_i | p_{i\pm 1}) = (p_i - f^m)(b_i - b_{i-1}) - F. \tag{4}$$

Differentiating (4) with respect to p_i, and employing Theorem 6 in Economides (1989), we have a symmetric equilibrium mill price

$$p^m = \frac{c}{n^2} + f^m,$$

and the profit

$$\pi_i(p^m | p^m) = \frac{c}{n^3} - F, \tag{5}$$

both of which are the same for all firms.

2c. MD pricing

Finally, consider the case that odd-number firms choose the mill pricing strategy while even ones choose the discriminatory pricing strategy. The number of firms n is large enough and is even. We call it MD pricing.

The odd-number firms are sandwiched between even-number firms whose price schedule is given by (1). Let b_i be the market boundary as defined in the preceding subsection, and p^{md} be the mill price of firm i, which is odd. Equating the full prices, we have

$$b_{i-1} = \frac{p^{md} - f^d + c(x_i^2 - x_{i-1}^2)}{2c(x_i - x_{i-1})} \quad \text{and} \quad b_i = \frac{f^d - p^{md} + c(x_{i+1}^2 - x_i^2)}{2c(x_{i+1} - x_i)}.$$

The odd-number firm maximizes its profit with respect to its mill price as follows:

$$\underset{p^{md}}{\text{maximize}} \;\; \pi_i(p^{md} \,|\, p^d) = (p^{md} - f^m)(b_i - b_{i-1}) - F.$$

Computing the first-order condition for maximum, we obtain the mill price

$$p^{md} = \frac{c(x_{i+1} - x_i)(x_i - x_{i-1})}{2} + \frac{f^d + f^m}{2}. \tag{6}$$

Using (6) and the (local) maximizer $x_i^* = (x_{i+1} + x_{i-1})/2$, the profit of each firm is then given by

$$\pi_i(p^{md} \,|\, p^d) = \frac{[c + (f^d - f^m)n^2]^2}{4cn^3} - F. \tag{7}$$

On the other hand, given the mill pricing of (6) by odd-number firms, the price schedule of even-number firms is the same as (1), and its profit is shown to be

$$\pi_i(p^d \,|\, p^{md}) = \frac{[3c - (f^d - f^m)n^2]^2}{8cn^3} - F.$$

3. Sustainability of equilibrium

Let us investigate the sustainability of equilibrium.

3a. Discriminatory pricing

Suppose that every firm takes discriminatory pricing but one firm changes its strategy to mill pricing. The mill price and the profit of its firm should be identical to (6) and (7). The sustainability condition is then given by

$$\pi_i(p^{md} \,|\, p^d) \le \pi_i(p^d \,|\, p^d). \tag{8}$$

Using (3) and (7), inequality (8) is shown to be equivalent to

$$
\begin{cases}
f^d \le f^m \\
\text{or} \\
f^d > f^m \quad \text{and} \quad n \le \left(\dfrac{(\sqrt{2}-1)c}{f^d - f^m} \right)^{1/2} \equiv n_1 .
\end{cases}
\tag{9}
$$

3b. Mill pricing

Next, consider the situation that every firm takes mill pricing but one firm changes its strategy to discriminatory pricing. The profit of its firm is computed as:

$$
\pi_i(p^d|p^m) = \frac{[2c-(f^d-f^m)n^2]^2}{2cn^3} - F .
$$

The sustainability condition is

$$
\pi_i(p^d|p^m) \le \pi_i(p^m|p^m),
$$

which is equivalent to

$$
f^d > f^m \quad \text{and} \quad n \ge \left(\frac{(2-\sqrt{2})c}{f^d - f^m} \right)^{1/2} \equiv n_3 . \tag{10}
$$

3c. MD pricing

Finally, consider the sustainability condition when odd-number firms choose mill pricing while even ones choose discriminatory pricing. From subsection 3a, a firm surrounded by two discriminatory pricing firms selects mill pricing when

$$
\pi_i(p^{md}|p^d) \ge \pi_i(p^d|p^d)
$$

or

$$
f^d > f^m \quad \text{and} \quad n \ge n_1, \tag{11}
$$

which is the same as (8) except the direction of inequality.

A firm surrounded by two mill pricing firms with price p^{md} would select discriminatory pricing only if

$$
\pi_i(p^d|p^{md}) \ge \pi_i(p^{mmd}|p^{md}),
$$

where

$$p^{mmd} = \frac{3c}{4n^2} + \frac{f^d + 3f^m}{4}$$

is the best reply against p^{md}.

This sustainability condition is equivalent to

$$f^d > f^m \quad \text{and} \quad n \leq \left(\frac{3(3-2\sqrt{2})c}{f^d - f^m} \right)^{1/2} \equiv n_2. \tag{12}$$

It should be noticed that $n_1 < n_2 < n_3$.

3d. Comparisons

Summarizing the results of (9), (10), (11) and (12), we can classify the cases in accordance with the number of firms as compared to the parameter values, and establish the following.

Proposition 1

(i) When $f^d \leq f^m$, each firm takes the discriminatory pricing strategy.

(ii) When $f^d > f^m$,

(a) if $n \in (0, n_1]$, each firm takes the discriminatory pricing strategy.

(b) if $n \in [n_1, n_2]$, each firm takes the MD pricing strategy.

(c) if $n \in [n_3, +\infty)$, each firm takes the mill pricing strategy.[1]

Several implications are drawn from Proposition 1. In the first place, the discriminatory pricing is likely to take place. It prevails when the marginal cost of the discriminatory pricing firms (f^d) is lower than that of the mill pricing ones (f^m). Moreover, it prevails even when the former marginal cost is higher insofar as the number of firms n is small, and/or the transportation cost c is large.

[1] In addition to the above three kinds of spatial arrangements of pricing strategies, there may exist other arrangements when n is in the vicinity of n_2 or n_3. For example, it is an equilibrium that firms i=3k take mill pricing, and firms i=3k+1 and 3k+2 take discriminatory pricing, where k is the natural number.

Roughly speaking, *firms tend to adopt the discriminatory pricing strategy so long as the marginal costs between the two are not so different.*

Second, comparing (5) with (3), we know that the profit of mill pricing is always greater than that of discriminatory pricing. From Proposition 1, when n is small, each firm takes discriminatory pricing, leading to a smaller profit than the mill pricing case. As a result, each firm falls into Pareto inferior state in equilibrium like prisoners' dilemma. This is a similar finding by Thisse and Vives (1988).

Finally, since n_1, n_2 and n_3 are positively related to the transportation cost rate c, we can say as follows. As the transportation cost gets small and/or the number of firms gets large, the MD pricing emerges, and is replaced by the mill pricing in the end. We may infer from this that decreasing transportation cost together with diminishing entry barriers would lead to the change from the discriminatory strategy to the mill pricing strategy.

4. Long run number of firms and social optimum

4a. Long run equilibrium number of firms

If free entry is allowed, and the profit becomes zero in the long run equilibrium, then the zero profit condition determines the number of firms n endogenously.

In the discriminatory pricing case, setting the profit of (3) equal to zero, we have the equilibrium number of firms as

$$n^d = \left(\frac{c}{2F}\right)^{1/3}. \tag{13}$$

In the mill pricing case, setting (5) to zero, the equilibrium number of firms is

$$n^m = \left(\frac{c}{F}\right)^{1/3}. \tag{14}$$

In the MD pricing case, setting (7) to zero, we have two positive solutions for n. However, since the larger one does not satisfy the constraint of $b_i - b_{i-1} \in [0, 2/n]$, the smaller one is chosen as a unique equilibrium, which we denote

$$n = n^{md}. \tag{15}$$

Note that $n^d < n^{md} < n^m$ can be shown.

4b. Social optimum number of firms

The social optimum is obtained by minimizing the sum of the total transportation costs, the total fixed costs, and the total marginal costs of production. We therefore formulate as to

$$\underset{n}{\text{minimize}} \;\; \mathrm{TC}(n) = 2n\int_0^{1/2n} cx^2 dx + nF + \min(f^d, f^m). \tag{16}$$

Solving this yields

$$n^o = \left(\frac{c}{6F}\right)^{1/3}. \tag{17}$$

And, the pricing strategy with a lower marginal cost of production should be chosen.

4c. Welfare Comparisons

From (13), (14), (15) and (17), we confirm that

$$n^o < n^d < n^{md} < n^m.$$

Hence, as in Salop (1979), we can state the following:

Proposition 2

Whatever pricing equilibrium is attained, the equilibrium number of firms is too large as compared to the social optimum one.

In particular, the equilibrium number of firms is 82% larger than the optimum one in the mill pricing case (Economides, 1989), and 44% larger in the discriminatory pricing case. One may therefore say that there exist too many retail firms in the actual urban areas.

Next, let us compare the social total cost TC(n) of each pricing case by substituting (13), (14) and (17) into (16). Straightforward calculations yield

$$\mathrm{TC}(n^d) = \frac{7\cdot 2^{2/3}}{12} c^{1/3} F^{2/3} + f^d,$$
$$\mathrm{TC}(n^m) = \frac{13}{12} c^{1/3} F^{2/3} + f^m,$$
$$\mathrm{TC}(n^o) = \frac{6^{2/3}}{4} c^{1/3} F^{2/3} + \min(f^d, f^m).$$

Directly comparing the social total costs of the two equilibria, we obtain the following:

Remark 1

The mill pricing is more efficient than the discriminatory pricing when $\varphi > \varphi_0$, *and the reverse is true when* $\varphi < \varphi_0$, *where*

$$\varphi \equiv \frac{f^d - f^m}{c^{1/3} F^{2/3}} \quad \textit{and} \quad \varphi_0 \equiv \frac{13 - 7\cdot 2^{2/3}}{12} \cong 0.157.$$

Consider the parameter range of $\varphi \in (0, \varphi_0)$. Since φ is positive, the marginal cost of discriminatory pricing f^d is higher than that of mill pricing f^m. Nevertheless, the discriminatory pricing is socially more desirable than the mill pricing. This is because the smaller number of firms reduces the sum of the fixed costs in the discriminatory case in this parameter range. That is, the effect of the higher marginal costs is dominated by the effect of the lower total fixed costs.

Suppose that the marginal costs are relatively small and negligible as compared to the fixed cost and the transportation cost. Then, we can approximately say that the social total cost is 12% higher in the discriminatory pricing equilibrium than that in the optimum, and 31% higher in the mill pricing equilibrium than that in the optimum.

The next analysis is on consumers' surplus. Since consumers' demand for the good is inelastic here, the change in the full price is a direct measure of consumers' surplus. Interestingly, the following remark holds in each pricing equilibrium.

Remark 2

The social total cost of (16) is equal to the total (and average) full price, which is incurred by consumers.

Proof:

(a) Discriminatory pricing

Due to the free entry condition, the profit is zero. Put it differently, the total revenue is equal to the total costs of the firms:

$$2n\int_{1/2n}^{1/n}(cx^2+f^d)dx = 2n\int_0^{1/2n}(cx^2+f^d)dx + nF. \tag{18}$$

Now, the RHS of (18) is the same as the social total cost of (16), and the LHS of (18) is the total (or average) full price.

(b) Mill pricing

Due to the free entry condition of zero profit, we have

$$1\cdot p^m = 1\cdot f^m + nF. \tag{19}$$

Using (19), the social total cost of (16) is rewritten as

$$\mathrm{TC}(n) = 2n\int_0^{1/2n} cx^2dx + nF + f^d = 2n\int_0^{1/2n} cx^2dx + p^m,$$

in which the RHS is the total (and average) full price.

(c) MD pricing

This is the mixed case between (a) and (b), and is similarly shown. ■

Note that since the demand density is normalized to one here, the total cost (price) is the same as the average cost (price). From Remark 2, we can say the similar thing as Remark 1: the mill pricing is more desirable for consumers than the discriminatory pricing when $\varphi > \varphi_0$, and the latter is more desirable when $\varphi < \varphi_0$. The desirability means the low full price from a viewpoint of consumers' surplus.

5. Transition of long run equilibrium

From Proposition 1 together with (13)-(15), we have the following set of long run equilibrium conditions:

(1) discriminatory pricing is stable if $\varphi \in (-\infty, \varphi_2]$;

(2) MD pricing is stable if $\varphi \in [\varphi_2, \varphi_3]$;

(3) mill pricing is stable if $\varphi \in [\varphi_1, +\infty)$;

where $\varphi_1 \equiv 2-\sqrt{2} \cong 0.586,\quad \varphi_2 \equiv 2^{2/3}(\sqrt{2}-1) \cong 0.658,\quad \varphi_3 \equiv 3(3-2\sqrt{2})\left(\dfrac{10+6\sqrt{2}}{7}\right)^{2/3} \cong 0.983.$

Examining the above, we can classify the long run equilibria and establish the following proposition.

Proposition 3

(a) If $-\infty < \varphi \leq \varphi_1$, each firm takes the discriminatory pricing strategy.

(b) If $\varphi_1 \leq \varphi \leq \varphi_2$, each firm takes the discriminatory or mill pricing strategy.

(c) If $\varphi_2 \leq \varphi \leq \varphi_3$, each firm takes the MD or mill pricing strategy.

(d) If $\varphi_3 \leq \varphi < +\infty$, each firm takes the mill pricing strategy.

Figure 3 illustrates these four cases.[2]

[2] In addition, as mentioned in footnote 1, there may exist other spatial arrangements such as mill pricing for firms $i=3k$ and discriminatory pricing for firms $i=3k+1$ and $3k+2$.

From Remark 1 and Proposition 3, we observe the difference between market equilibrium and social optimum in the parameter range of $\varphi \in (\varphi_0, \varphi_1)$. Each firm chooses discriminatory pricing in equilibrium although mill pricing is more desirable for society as a whole. This is a so-called market failure. It is intuitively explained as follows. Since the marginal costs between the two pricings do not differ much within this parameter range, the relative disadvantage of the discriminatory pricing is not so big. However, the discriminatory pricing is more flexible in that it can vary the delivered price for each location. Hence, the discriminatory pricing becomes a dominant strategy in spite of its small handicap in the marginal cost.

We can read the impacts of the parameters on the pricing strategies from Proposition 3. The mill pricing strategy prevails for a large value of φ, which corresponds to small values of c and F and a large difference of $f^d - f^m$.[3] The impact of the difference $f^d - f^m$ on pricing strategy is straightforward, but that of c and F are not. So, let us investigate economic implications of the two parameters below.

In deciding pricing strategies, firms compare the equilibrium mill price ($p^m = c/n^2 + f^m$) with the marginal cost of discriminatory pricing firms (f^d) because these two values determine the market boundaries. The parameters c and n are related to the former value, but not the latter one. This means first that as the transportation cost rate c gets small, the mill price p^m decreases. On the other hand, the cost structure of the discriminatory pricing firms remains unchanged. As a result, the mill pricing strategy becomes relatively advantageous, leading to its dominance. Second, when the entry cost F becomes small, entry would easily

[3] We can infer that the prevalence of mill pricing in the real world is attributed to high f^d, low f^m, low c, and low F.

take place. This increases the number of firms n, which indirectly contributes to a decrease in p^m since $p^m = c/n^2 + f^m$ holds. Therefore, a decrease in F as well as a decrease in c leads to prevalence of the mill pricing strategy.

We may say that when these costs go down, the market structure may look like monopolistic competition, where many small firms such as retail stores and restaurants are competing each other. However, when these two costs go up, the market structure may become oligopolistic. *In other words, goods with low costs are sold by many mill-pricing firms while goods with high costs are delivered by few price-discriminating firms.* Thus, the cost structure determines the market structure.

The question is whether these costs c and F increase or decrease over time. The technical progress in transportation reduces the transportation cost rate c. On the other hand, recent tendency of various deregulations would remove entry barriers, and hence reduce the entry cost F. These two factors contribute to an increase in the number of firms n, and then the dominance of the mill pricing strategy. However, F may tend to grow over time if increasing returns to scale in production and in sales are getting more important. Large R&D expenditure on sunk capital investments is an example. If this factor is stronger than the other two, then the market is occupied by few big firms taking the discriminatory pricing strategy.

Finally, it is observed from Figure 3 that there exist multiple equilibria when $\varphi \in [\varphi_1, \varphi_3]$. In such cases, initial conditions dictate which pricing equilibrium is realized. To see this, let us examine two representative situations below.

Case I: φ is initially small and is increasing over time.

We know from Proposition 3(a) that initially the discriminatory pricing prevails for a small value of φ. However, as φ gets large and reaches φ_2, odd-number firms change its strategy to mill pricing. And so, the discriminatory pricing is replaced by the MD pricing. When φ exceeds φ_3, even-number firms alter its strategy to mill pricing too. That is, the mill pricing equilibrium predominates.

Case II: φ is initially large and is decreasing over time.

The parameter φ changes in a reverse direction of Case II. From Proposition 3(d), for a large φ each firm selects the mill pricing initially. Such a mill pricing equilibrium persists until φ reaches φ_1. When φ becomes smaller than φ_1, each firm changes its mill pricing strategy to the discriminatory one all at once.

Comparing the two cases, we observe a so-called *hysteresis* in that the spatial arrangements of pricings differ between the two directions when $\varphi \in (\varphi_1, \varphi_3)$.[4]

6. Conclusion

We have analyzed a spatial oligopoly, where firms compete in location and in pricing strategy. Consumers are uniformly distributed over the unit-circumference of a circle. Firms select their location on the circumference of a circle in the first stage, and choose a pricing strategy in the second stage. Seeking subgame perfect Nash equilibrium, we have examined the sustainability of equilibrium. The following results were obtained.

First, firms tend to adopt the discriminatory pricing as a dominant strategy

[4] It should be noted that other spatial arrangements such as the one in footnote 2 do not appear in these two cases. It means that when the parameter φ changes monotonically, the spatial configuration is uniquely determined.

so far as the marginal costs between the mill and discriminatory pricing strategies do not differ much. It is not only Pareto inferior for each firm, but also a market failure from a social welfare point of view. Second, whatever the pricing strategy is attained, the equilibrium number of firms is too large as compared to the social optimum one. Third, the mill pricing strategy may become prevalent in the future due to improvements in transportation technology and deregulations of market entry. Finally, we found multiple equilibria and a hysteresis in the spatial arrangements of pricing strategies.

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Figure 1 Discriminatory Pricing

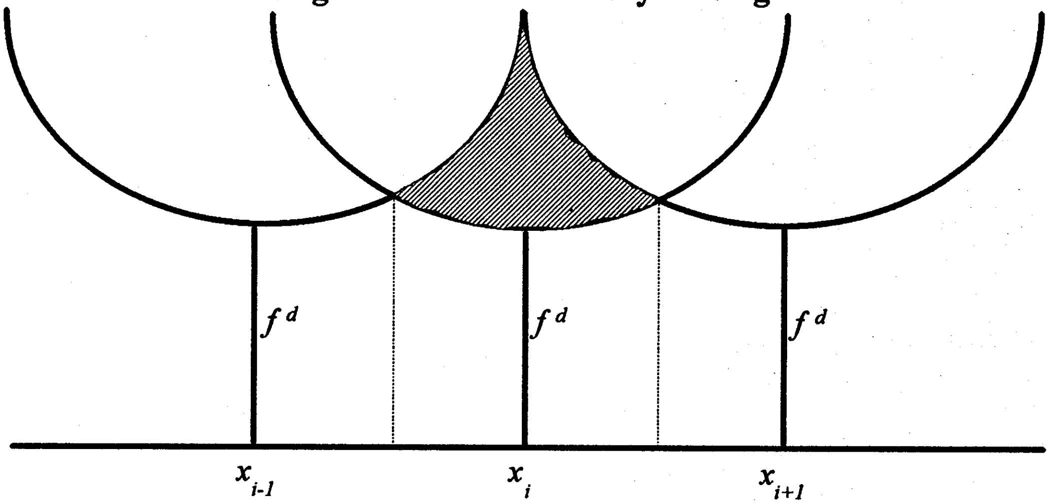

Figure 2 Mill Pricing

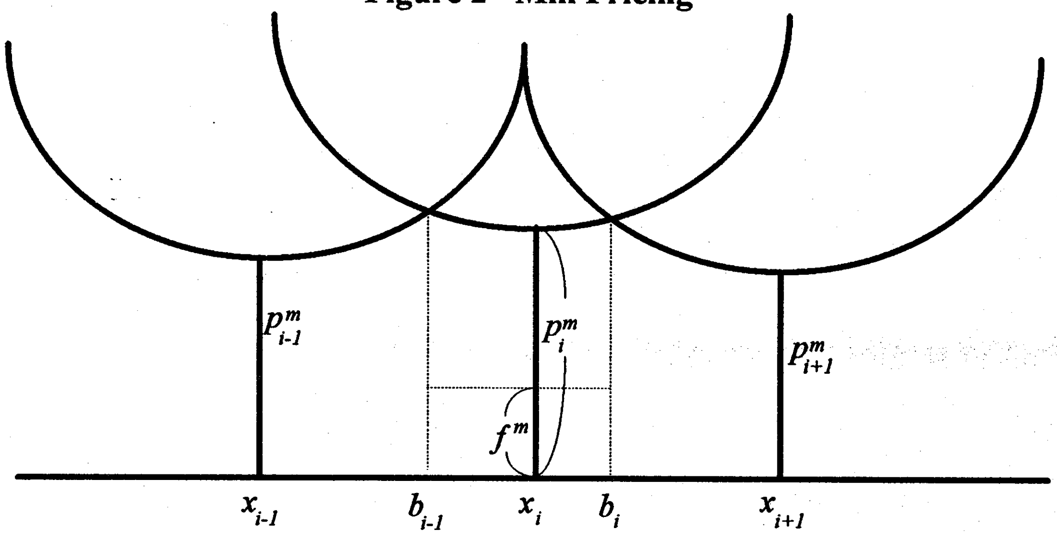

Figure 3 Parameter Change and Spatial Arrangements of Pricing Strategies